J Low Temp Phys (2012) 167:1087–1092
DOI 10.1007/s10909-012-0587-6

Experimental Characterization of Space Charge in IZIP Detectors

T. Doughty · M. Pyle · N. Mirabolfathi · B. Serfass · O. Kamaev · S. Hertel · S.W. Leman · P. Brink · B. Cabrera · B. Sadoulet

Received: 2 August 2011 / Accepted: 30 January 2012 / Published online: 16 February 2012

Abstract Interleaved ionization electrode geometries offer the possibility of efficient rejection of near-surface events. The CDMS collaboration has implemented this interleaved approach for the charge and phonon readout for our germanium detectors. During a recent engineering run with negligible ambient radiation, the detectors were found to lose ionization stability more quickly than expected. This paper summarizes studies done in order to determine the underlying cause of the instability, as well as possible running modes that maintain stability without unacceptable loss of livetime. Additionally, first results are shown for the new version IZIP mask which attempts to improve the overall stability of the detectors.

Keywords Germanium · Charge trapping · CDMS

For the SuperCDMS Collaboration.

T. Doughty (✉) · N. Mirabolfathi · B. Serfass · B. Sadoulet
University of California at Berkeley, Berkeley, CA 94720, USA
e-mail: tdoughty1@berkeley.edu

M. Pyle · B. Cabrera
Stanford University, Palo Alto, CA 94305, USA

O. Kamaev
Queen's University, Kingston, Ontario, Canada

S. Hertel · S.W. Leman
Massachusett's Institute of Technology, Cambridge, MA 02139, USA

P. Brink
SLAC National Accelerator Laboratory, Menlo Park, CA 94309, USA

1 Introduction

The Cryogenic Dark Matter Search [1, 2] (CDMS) collaboration employs instrumented germanium crystals which allow simultaneous measurement of both the phonon and ionization signals from particle collisions. The ratio of energy between these two channels provides event by event discrimination for electron and nuclear recoils in the target material. In previous phases of this experiment, near-surface events were the primary background. For these events, the hot charge carriers near the surface are able to back diffuse into the electrode, lowering the collected charge signal and causing electron recoils to mimic nuclear recoils. As a solution to this near-surface event problem, we have implemented an interleaved electrode design (IZIP) [3–5]. The IZIP detector has very large lateral fields near the surface while maintaining a smaller uniform field across the bulk because the interleaved electrodes are run at different biases. In this configuration, the charges produced by near surface events will be transported laterally along the surface of the detector so that all charges are collected on a single side while events in the bulk are collected on both sides. This design allows a clear definition of the fiducial volume and rejection of the near-surface background events, while maintaining strong yield rejection.

During an engineering run in Soudan (Minnesota) underground facility, the IZIP detectors showed faster than expected instability in both ionization yield and longitudinal ionization partition. Such effects had been noticed at surface test facilities, but were attributed to the high radiation environment which produces significant space charge in the large crystals (630 g). In Soudan's low background environment, the stability of the ionization signals did not scale with the event rate as was expected. Many recent studies by the CDMS collaboration have focused on this issue. These include Monte Carlo simulations of charge trapping in the detector [6], as well as efforts to improve crystal screening procedures [7], both of which are published in these proceedings. We report here on the characterization of the space charge distribution and methods for overcoming the ionization instability problem.

2 Experimental Setup

The IZIP is a 3 inch diameter by 1 inch thick cylindrical crystal. It is instrumented with interleaved ionization rails for charge collection and W transition edge sensors (TES) coupled to Al fins for athermal phonon collection on both faces. We report here on two versions of the electrode design: v4 with 8 μm wide electrodes and v5 with 40 μm. In standard configuration, the IZIP detectors are biased with the ionization rails on side 1 at +2 V and the rails on side 2 at −2 V while the phonon bias lines are kept at ground. The detectors were exposed to a 40 Hz source of Ba-133. At the start of any dataset, the detector is flashed with 940 nm light while the charge electrodes are grounded. This light is above the energy of the bandgap and acts to clear the space charge and effectively reset the detector.

Two important derived quantities used as a measure of the charge discrimination properties of the detectors are ionization yield and ionization partition. The ionization yield is the ratio of total collected charge energy to the recoil phonon energy.

This provides our primary tool for recognition of nuclear recoils. The yield is normalized so that electron recoils have a value of 1, while nuclear recoils have a value roughly a third of that. The partition (1) is useful to describe the surface and fiducial (bulk) portions of the crystal and provides the most powerful rejection of near-surface events.

$$\text{Partition} = \frac{Q_1 - Q_2}{Q_1 + Q_2} \tag{1}$$

where Q_1 is the total charge collected on the top surface electrodes and Q_2 is the total charge collected on the bottom surface. A partition value of ± 1 corresponds to collection solely on one surface. For an ideal crystal, a partition value of 0 means equal collection on both sides of the crystal which corresponds to events in the fiducial volume (bulk) of the crystal. The spread seen in the bulk partition values is due to charge trapping in the crystal.

3 Results

3.1 Charge Buildup

This paper discusses the ionization stability for two version 4 detectors (with 8 µm ionization electrodes): G47 and G48, as well as a new mask detector, G41 (v5, 40 µm ionization electrodes). Each of the detectors studied in this paper was put through the same basic study. First, the detector was biased for an hour (2 hours for G41) at which point it was grounded for a half hour. After flashing the detectors, this same process was repeated for the opposite polarity.

Each individual detector crystal shows unique stability characteristics. We have not yet been able to establish any correlation with crystal properties or processing details. G48 was the most stable detector tested in the recent CDMS engineering run (Fig. 1). Over the hour bias period, there is no significant decay in the ionization yield, but we begin to see a small increase in trapping evidenced by the spread in the bulk partition. While this is a small effect, it leads to a time dependance in the discrimination ability of the detector. By comparison, the worst detector (G47—see

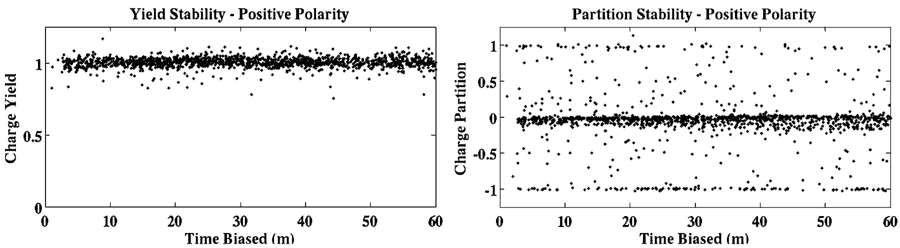

Fig. 1 The figure on the *left* shows the ionization yield for G48. The figure on the *right* shows the charge partition. G48, the most stable detector tested, showed little yield instability in an hour period. The spread of the z partition grows slightly with time corresponding to a small increase in trapping

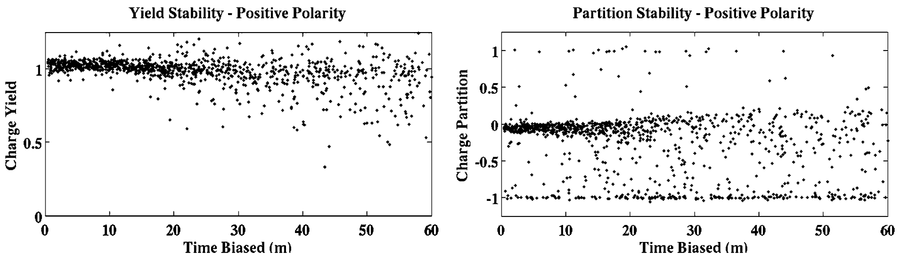

Fig. 2 The figure on the *left* shows the ionization yield for G47. The figure on the *right* shows the charge partition. Within 15 minutes, both quantities have decayed significantly which corresponds to a loss of discrimination capability. The partition quantity decays most strongly towards negative values which corresponds to less collection on the positive electrode. This means the instability is especially true for electron transport and collection

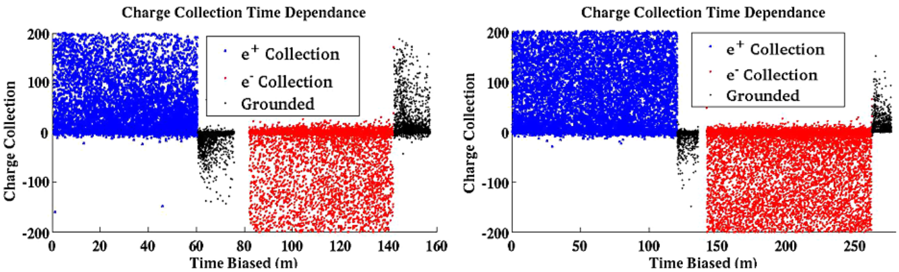

Fig. 3 (Color online) The figure on the *left* shows the amplitude for bulk events from a single ionization electrode from G47 (v4). Initially on grounding, the events have inverted polarity due to charge buildup near the electrodes. The magnitude of the pulses appears to decrease with time. This corresponds to the dissipation of the charge buildup while the detector is grounded. The figure on the *right* shows the amplitudes for G41 (v5). In twice the overall bias period, G41 builds up a smaller counter electric field due to the wider charge electrode

Fig. 2) loses stability in less than 15 minutes, clearly evident in both yield and partition. After this time, the discrimination ability of the detector for both recoil type and near-surface events is lost.

The charge instability is most likely due to a decrease in the overall fields due to the buildup of charges. This effect is demonstrated in the grounded data. Following the long bias period, the polarity of the pulses immediately reverses when grounded (see Fig. 3—left). This reversal is true for both events near the crystal surface as well as in the bulk of the crystal. This is consistent with charges of opposite polarity trapped near the ionization electrodes. When biased, these trapped charges shield the electrodes and decrease the overall field of the crystal leading to increased trapping. The source of these charges is still being studied. In order to effectively shield the electrode, we need many more charges than are produced by particle collisions. Furthermore, the rate at which the ionization signal loses stability is partially independent of event rate. The most likely source of this charge is current across the surface of the crystal due to the high fields in the IZIP. When the detectors are biased, the low frequency noise increases possibly due to shot noise of this current. The increase in the power spectrum when biased corresponds to shot noise from an electron current

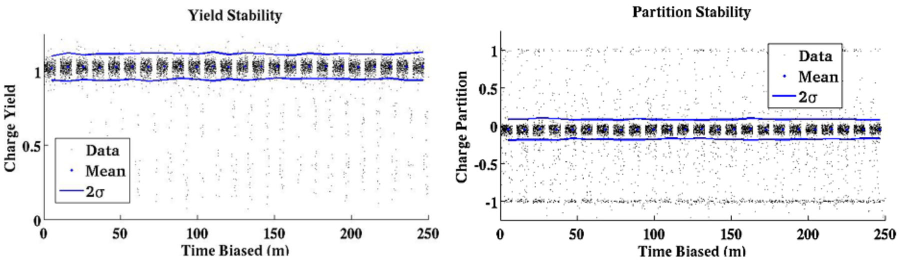

Fig. 4 (Color online) The ionization yield and partition for G47 with the grounding scheme implemented. There appears to be no degradation during the entire 4 hour bias period

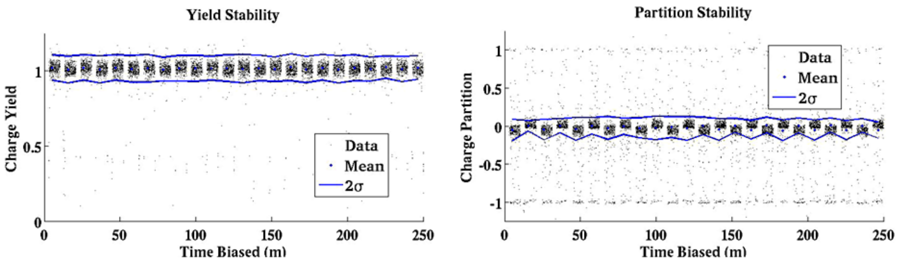

Fig. 5 (Color online) The ionization yield and partition for G47 with the polarity flipping scheme implemented. Again, there appears to be no degradation during the entire 4 hour period

of 10 pA. This current leads to a charge buildup even in the low background rates in Soudan. Once the detector is grounded, additional charges are no longer produced and the charge buildup dissipates on a timescale of minutes (Fig. 3). In surface facilities, high event rates help to clear the charge buildup in place of the LED flash. Further study is planned to understand this effect in low background environments.

3.2 Solutions

We cannot leave the IZIP detectors biased for long periods of time as done with previous detector types. However, preliminary studies at a surface test facility have found two simple running methods that can allow the detector to run for long periods with only modest loss in livetime. First, as suggested by the decay in bulk events seen in Fig. 3, grounding the detector for short periods of time can help to clear out the charge buildup. We biased G47 in the standard configuration for 7.5 minutes, then grounded the detector for 2.5 minutes. This cycle was repeated for a four hour period during which there is no significant decay in either yield or partition (Fig. 4).

Beyond simply grounding the detector, reversing the polarity of the crystal may also help to maintain stability. Figure 5 shows the ionization stability for G47 when the detector bias polarity was flipped following each 2.5 minute grounding period. We see the partition value oscillate slightly because the charge carriers are collected on changing sides, but the overall affect is to maintain the stability of the detector over the same period. Either simply grounding the detector or flipping the polarity along with grounding both appear to preserve the high discrimination of the G47, the most unstable detector, while maintaining 75% livetime. For more stable detectors, such as G48, the corresponding loss will likely be lower.

In addition to a new running mode that improves the charge stability for all detectors, we also implemented a new ionization electrode design to improve future detectors. A likely culprit for the charge buildup was the narrow (8 μm) electrodes of the IZIP v4. Smaller surface area electrodes can more effectively be shielded by trapped charges which lowers electric fields in the crystal. Moreover the larger fields around a narrow electrode could lead to larger injection currents. In order to address this issue, the IZIP v5 (40 μm) was developed. Following a similar approach for the v4 detectors, G41 (v5) was biased for 2 hours, then grounded. The grounded data shows a similar pattern for both types, but the new mask detectors are able to maintain stability for longer periods of times before developing the counter field. Further studies must be done in order to better understand these effects, but it appears that trapped charges near the ionization electrodes are one cause of the ionization instability that can be mitigated by increasing the electrode width.

4 Conclusion

While the charge instability remains a challenge in implementing the IZIP detectors, we have made significant progress in addressing this issue. A new mask with 40 μm ionization rails helps to reduce the charge trapping under the electrode. Additionally, studies at the UC Berkeley surface test facility have identified possible running modes for the previous design. By grounding frequently or reversing bias polarity, we are able to maintain sufficient charge stability with only a modest loss in detector livetime. We will be testing these biasing schemes in a low background environment with the 15 detectors that we plan to deploy to Soudan in October 2011.

Acknowledgements This work is supported by the United States Department of Energy grant DE-AC02-76SF00515 and the United States National Science Foundation awards 0705052, 0902182, 1004714, and 0802575.

References

1. Z. Ahmed et al., Science **327**, 1619–1621 (2010)
2. Z. Ahmed et al., Phys. Rev. Lett. **106**, 13102 (2011)
3. P.L. Brink et al., Nucl. Instrum. Methods A **559**, 414–416 (2006)
4. A. Broniatowski, in *AIP Conf. Proc., LTD 13*, vol. 1185, (2009), p. 219
5. M. Pyle et al., in *AIP Conf. Proc., LTD 13*, vol. 1185, (2009), p. 223
6. S.W. Leman et al., Time evolution of electric fields in CDMS detectors. J. Low Temp. Phys. (2012). doi:10.1007/s10909-012-0465-2. Proceedings LTD14
7. B. Shank, J. Yen, Temperature dependent I–V and resistance characterization of SuperCDMS germanium crystals. J. Low Temp. Phys. (2012). doi:10.1007/s10909-011-0449-7. Proceedings LTD14